Concepts of Thermodynamics
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Lecture – 08
Properties of Pure Substances
(Contd.)

Hello all and welcome to this lecture on Concepts of Thermodynamics. In today's lecture we will solve a problem by the aid of a computer which you might have already solved by hand that is by using a table.

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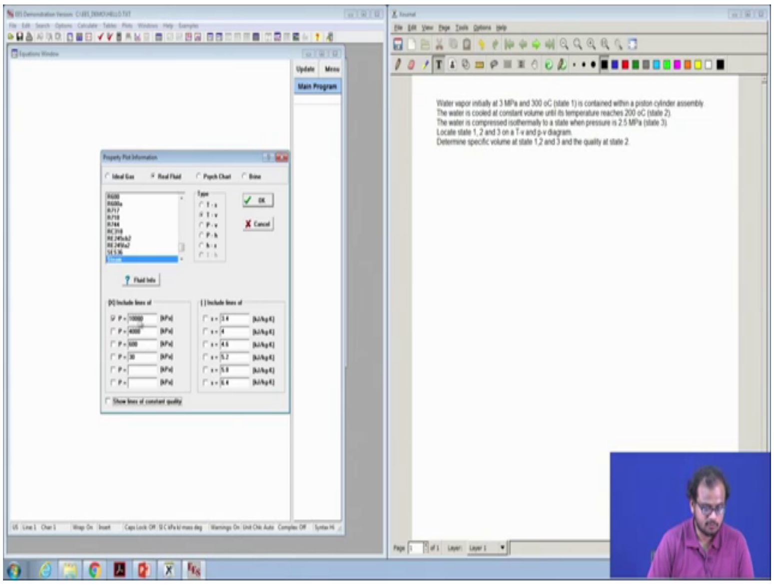

So, we will launch TES and I will open a new file, just the font size is problem is as follows; water vapor initially at 3 mega Pascal and 300 degree Celsius is contained in a piston cylinder arrangement. The water is cooled at constant volume until the temperature reaches 200 degree Celsius which is state 2, water is compressed isothermally to a state 3 by the pressure is 2.5 mega Pascal, the task is to locate states 1, 2 and 3 on the T v and p v diagram and we must determine the specific volume at states 1, 2 and 3 and the quality at state 2.

So, before proceeding it is worthwhile to quickly see the property plot for steam so, that we can make a nice estimate. So, we are going to plots property plots we got a steam and we draw p or T v diagram let us T v diagram and let us include the line of p v diagram and let us include the line of 3 mega Pascal. So, 3 mega Pascal in kilo Pascal is 3000. So, we have to plot property plot and we have to switch off the isentropic lines and constant quality lines we just want to see the 3 mega Pascal line in a T v diagram.

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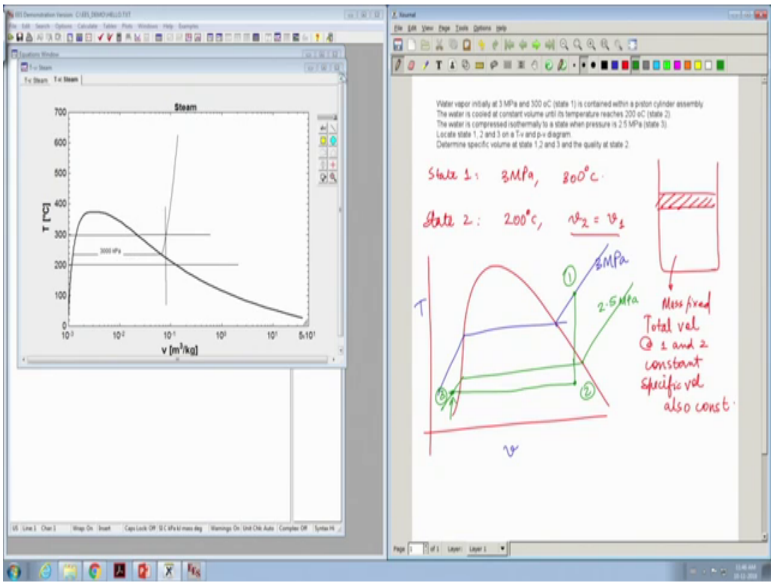

So, this is the diagram. So, we have the condition where it is 3 mega Pascal and 300 degree Celsius so, this 3 mega Pascal and 300 degree Celsius. So, if you look into this figure 300 degree Celsius is this line and it intersects the 3 mega Pascal line over here. So, the state 1 is superheated vapour, then it is cooled to 200 degree Celsius in an isochoric manner, state 2 is 200 degrees Celsius and v 2 the specific volume is equal to v 1 because there is no escape of mass. So, in a piston cylinder arrangement the mass is fixed and so, because the total volume remains constant between states 1 and 2 the specific volume is also constant so, that is the logic we will use.

So, if the total mass is constant and the specific volume and the total volume is constant then; obviously, specific volumes are equal thus v 2 equal to v 1. So, then from this particular point over here the line will move along this axis because it is a constant volume process. So, we expect that the process will look something which is a vertical line it will go up until it hits, it will go up until it hits the 200 degree Celsius line. So, we will reach a point which we expect to be in the 2 phase region in the saturated dome after this it is compressed isothermally to a pressure of 2.5 mega Pascal. So, it will move along a isothermal. So, it will move along this line up until reaches the 2.5 mega Pascal line.

So, if we draw it by hand. So, this is the 3 mega Pascal line over here let us draw it in blue. So, this is T and this is v. So, quite naturally that 2.5 mega Pascal will be at a lower point because, we have already seen the T side and v side are monotonous and linearly increasing. So, this is 2.5 I have exaggerated how this looks. So, it start somewhere over here and then it goes down iso actually we need to know what the pressures are, but anyway maybe it goes below 2.5.

So, state 1 is like this, state 2 is like this and then it goes in a isothermal manner until it reaches maybe this 2.5 ok, this is how maybe it looks like. So, the exact nature we will see, but it is good to have a physical picture before attempting the problem. So, that can be easily done if you have a look into the property plot.

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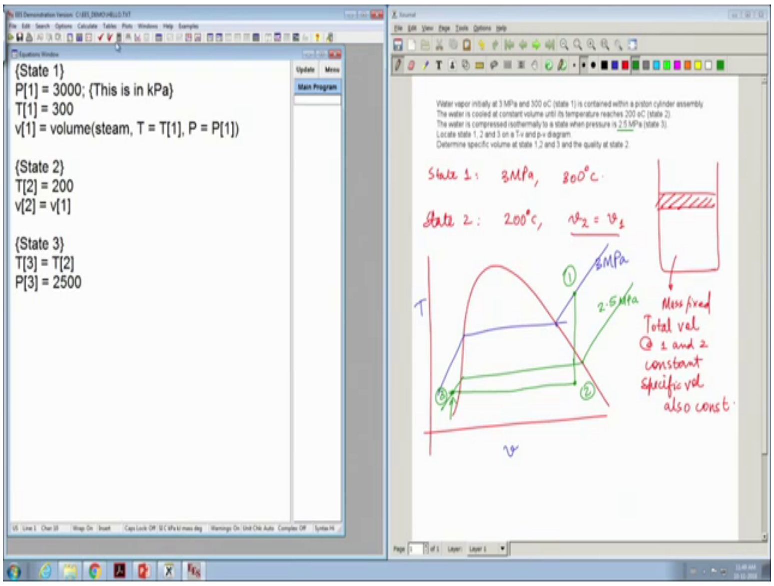

So, let us proceed. So, state 1 is P equal to sorry is defined inside an array. So, that it will be convenient for us to plot P 1 equal to 3000 this is in kilo Pascal.

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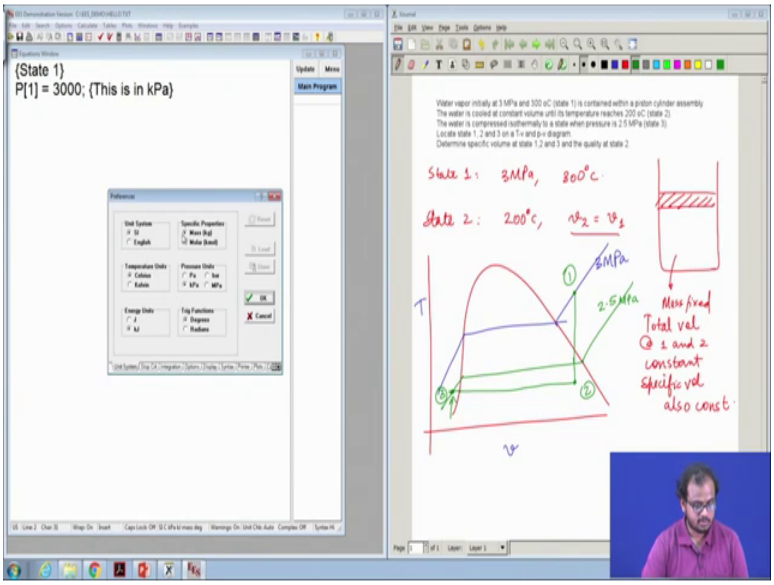

Because we recall the units over here that the pressure is in kilo Pascal; if we choose the pressure to be mega Pascal we can directly write a 3. But, right now it transact 300 kilo Pascal and the temperature is given as 300 degree Celsius.

Now, state 2 is simply T 2 is given to us as 200 degree Celsius and the only other information that we know is v at 2 is equal to v at 1 nothing, but saying that the specific volume at 2 is equal to the specific volume at 1. And, thus we need to actually determine the specific volume at 1 thus v 1 equal to volume a steam T equal to T 1 and T equal to P 1. I repeat again that the function volume requires as an input working fluid and then command of the form T equal to something comma P equal to something, I mean you need 2 independent properties to be fed to this function.

In this case it is T and P, it could be quality and something, but here it is superheated. So, we can use directly T and P. So, T equal to something I could have directly written here 300, but it is a good programming practice to write here the variable declare the variable somewhere else. So, that you do not have to repeat it again and again ok. So, volume steam T equal to T 1 and P equal to P 1. So, this gives us the volume at state 1 and with the help of this we have obtained the volume at state 2.

State 3 is such that it is a isothermal process and thus T at 3 will be equal to T at 2 and we know that it is isothermally compressed to a pressure of 2.5 mega Pascal isothermally compressed to a pressure of 2.5 mega Pascal ok. So, thus P 3 is equal to 2500.

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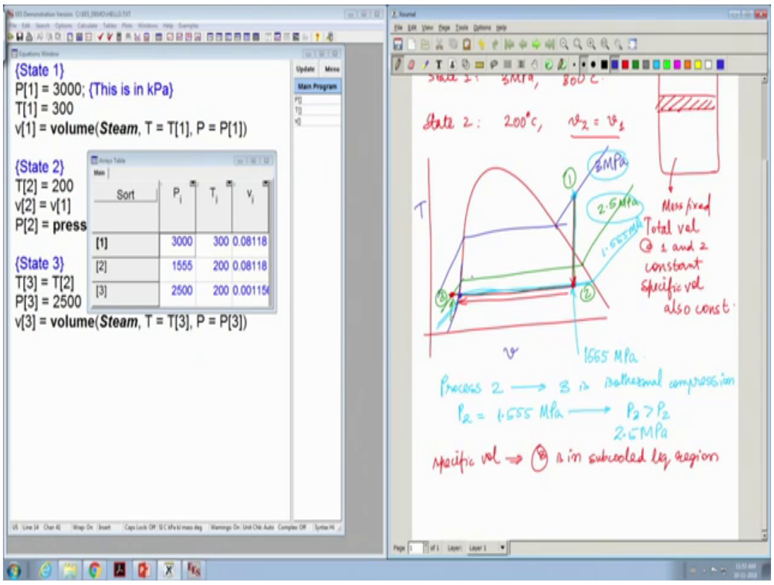

So, let us see if we run this we have obtained all the various quantities, in order to plot state points 1, 2 and 3 on the p v and the T v diagram we need to know the volumes and the pressures at all the 3 points. So, let us evaluate the pressure at state 2. So, clearly in this case we have 2 independent quantities which are T and v and thus in order to obtain the pressure we have we recall that we need 2 independent quantities which are temperature and volume in this case. I mean we will see later on that there can be any other quantities, but they need to be 2 independent quantities and the in the dome for example, you cannot make use of temperature and pressure to find out all the properties because temperature and pressure are related they are not independent we have already seen this.

Correspondingly v 3 is equal to volume steam T equal to T 3 and P equal to P 3. So, if we solve this ok. So, thus we have obtained that the pressure is 1555 or the state 0.2. So, naturally this point is that 1.55 mega Pascal as we suspected. So, this line is 2.5 mega Pascal, this line is 3 mega Pascal. So, there is a line like this sorry like this is 1.555 mega Pascal and the 0.1 goes first to this lower pressure upon which when you cool it, when you are compressing it see you are compressing the fluid from state 2 to 3 process 2 to 3 is isothermal compression and P 2 we have just found out is 1.555 mega Pascal.

So, when you compress something it is only natural that the pressure will increase. So, you obtain P 3 which is larger than P 2. So, here P 3 was given to us as 2.5 mega Pascal and thus P 2 to had to be lower than 2.5 mega Pascal. And thus we already without even actually getting the values we could estimate that yes it would start somewhere at 0.1 then it would go merrily to some pressure which is lower than 2.5 mega Pascal then when it is compressed it reaches the 2.5 mega Pascal line alright.

And the fact that the specific volume has suddenly increased see the specific volume was certainly decreased it was 0.08, 0.08 and 0.001. So, if we recall that the density of water is somewhere around 1000. So, specific volume is one by density. So, that implies this is in the sub cooled region. So, the specific volume does indicate that 0.3 it is in sub cooled liquid which we have already guessed because 0.2 was at 1.555 if we fix the temperature we cannot go to a higher pressure unless we go to a sub cooled region. So, up until we compress till the edge of the dome. So, the edge of the dome is here till this point the pressure also remains constant because we know that in the dome.

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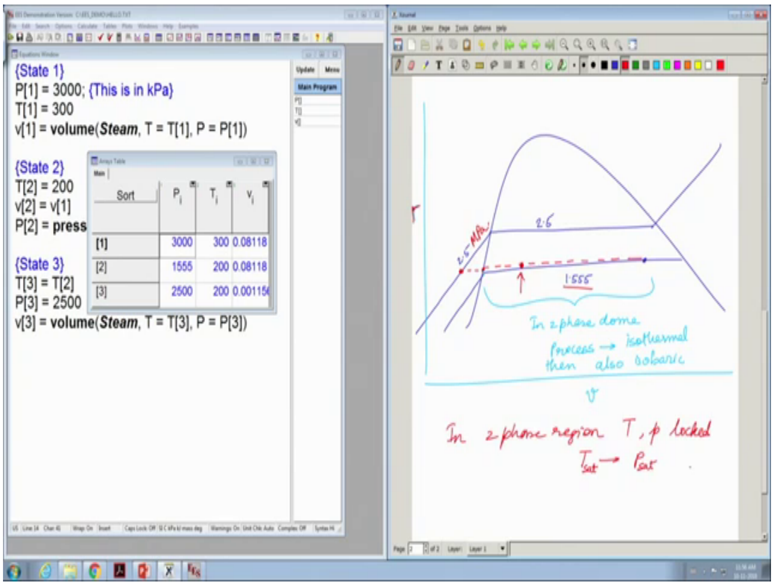

So, suppose this line is 1.555 and this line is 2. 5, we started somewhere over here we know that as long as I remain inside the 2 phase dome on the saturated dome if process is. So, this is the T axis this is the v axis, if the process remains isothermal then inside the dome it is also isobaric. And if at constant temperature you now increase if at constant temperature. If you keep reducing the volume you now, start going into higher pressures because you are travelling like this because if the temperature is constant you have to go in a horizontal manner. And, then you start going from a pressure of 1.555 to something higher than that and then eventually you hit something which is at a higher pressure you hit the 2.5 mega Pascal line. So, this is how that compression leads to an increase in pressure.

If there was no increase in pressure and it was in the compressed it and if it is compressed then it will indicate that you are still in the 2 phase zone. So, for example, if the compression was done up until this point if the compression was isothermal. And, if it is done up until this point then you would see no change in the pressure because you are still in the 2 phase region. In 2 phase region the temperature and pressure are locked which is to say given a certain temperature you know what that pressure is and we have already seen that this is called as the saturation temperature and a saturation pressure ok. So, enough of schematics let us see actually how we can plot using es ok. So, try to follow the logic. So, let us go to plots.

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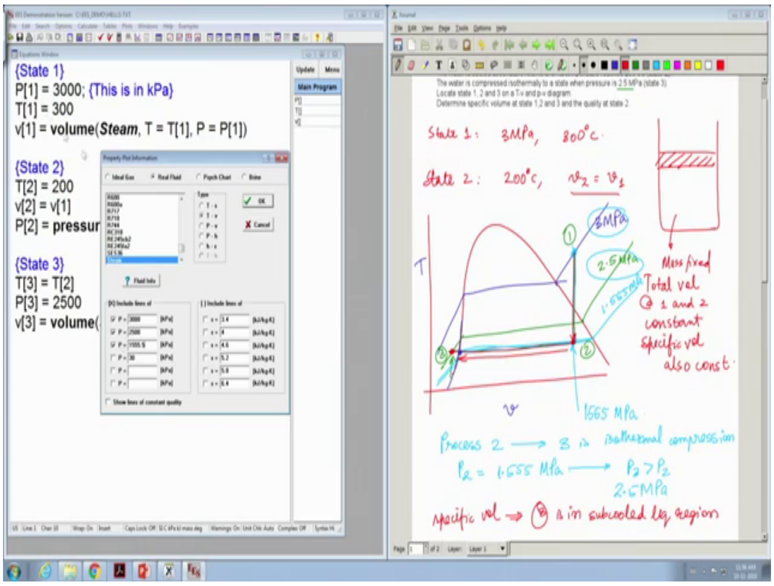

Let us draw the property plot of steam on the ts and let us include certain lines let us include the 3 mega Pascal line let us include the 2.5 mega Pascal line and let us include the 1000 this line. So, this is the plot that we obtain let us rescale it for our convenience.

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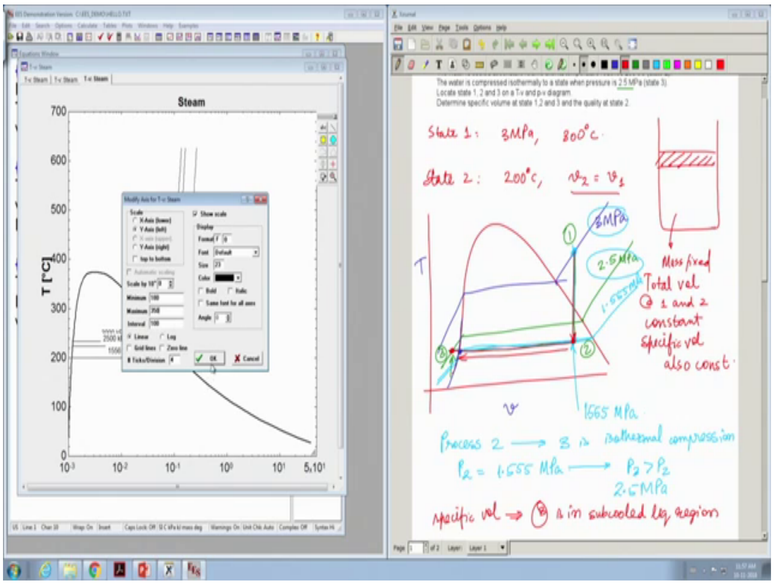

So, we do not need the access to the so large. So, the maximum goes to may be 0.2 on the x, the y axis maybe we can have from something like 180 and it can go to a maximum of may be 350.

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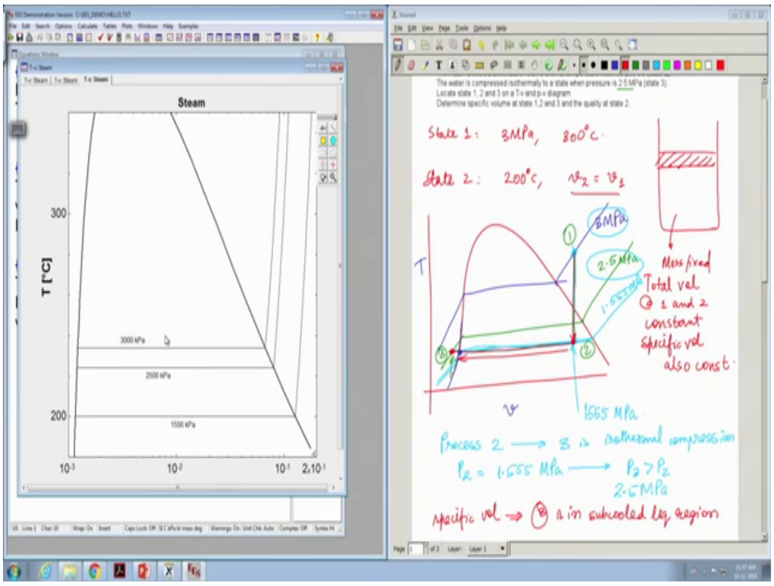

So, these are the 3 isobars this is the lowest isobar, this is the middle isobar and this is the other isobar. Let us have some space on the left hand side also, is too much space like this.

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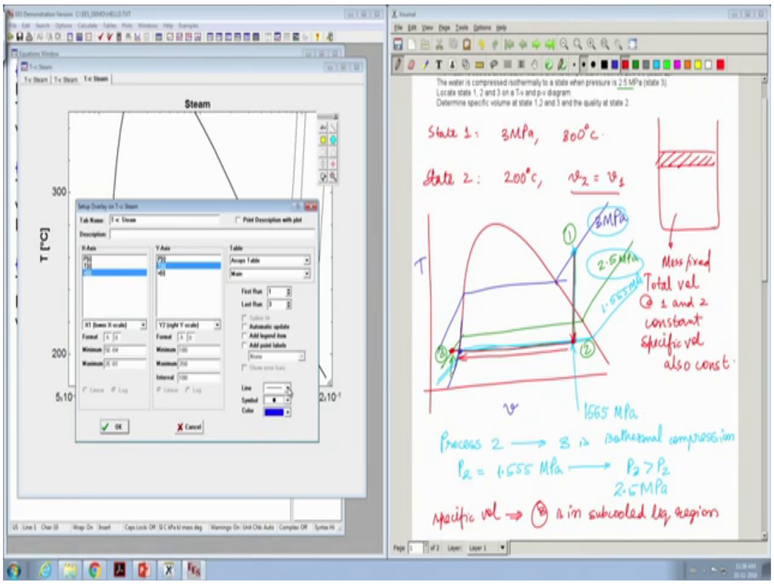

So, now let us go to plots overlay plot because we now want to overlay our points on to this property plot and we have T and v. So, on the x axis it is v, on the y axis it is T, let us draw them as field squares.

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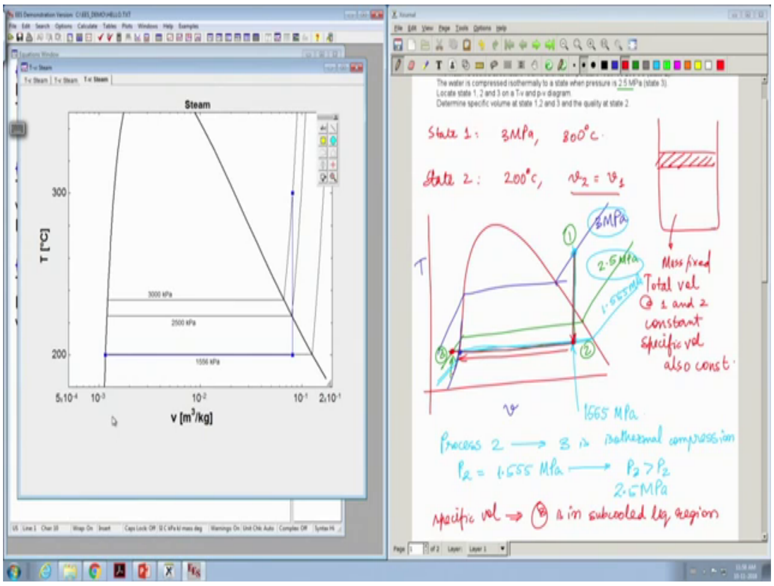

So, this is how it looks like. So, here it is just outside the 2.5 mega Pascal line has a very sharp slope on the super cooled region whatever I have shown here it is a schematic, but in reality it has a very very sharp slope. The meaning of the sharp slope will be clearer in the later classes, it just means that for a liquid del T del v is very large ok.

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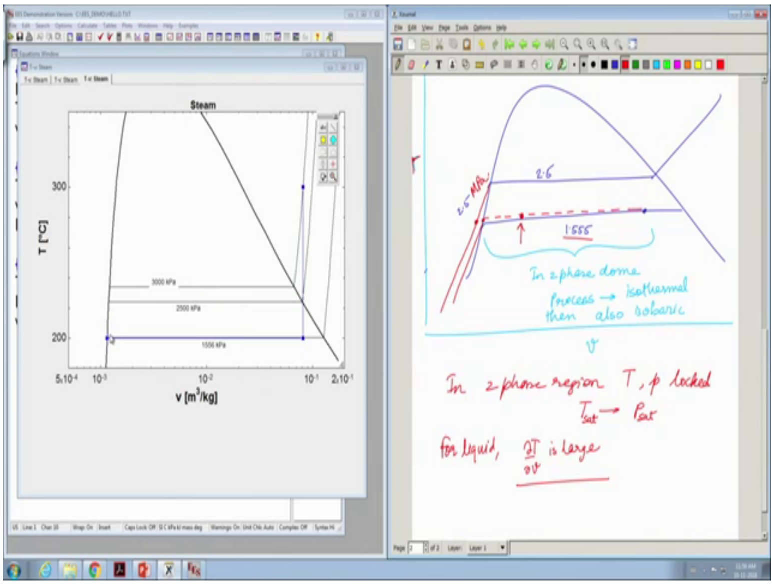

So, it almost goes like this and thus we do not need to travel so far you already reach this point over here that is why it looks almost like it is on the edge in reality it is outside the edge. So, this is the way the process goes we have started from one like here and we go to 2 at a lower pressure and then we go to this. So, this is how the plot looks it is at point 1 2 and 3 alright. So, we have we also asked to plot the p v diagram plot the state points in the p v diagram. So, let us go to plot property plot steam p v and let us include temperatures of 200 and 300 that is all we require.

So, let us change the limits on the y axis we can make do with the pressure above 1000 not even 1000 1200 milli and we do not need to go a so high, we are happy with 3500. On the X axis we are happy with the minimum, but the maximum maybe it needs to go to 0.2 may be as take it as 10. So, on this plot let us superpose the points overlay plot on the x axis we have volume, on the y axis we have the pressure. So, this is; obviously, wrong the process actually does not happen like this ok. So, what is the correct way to do it? So, this is the 200 degree Celsius line, this is the 300 degree Celsius line.

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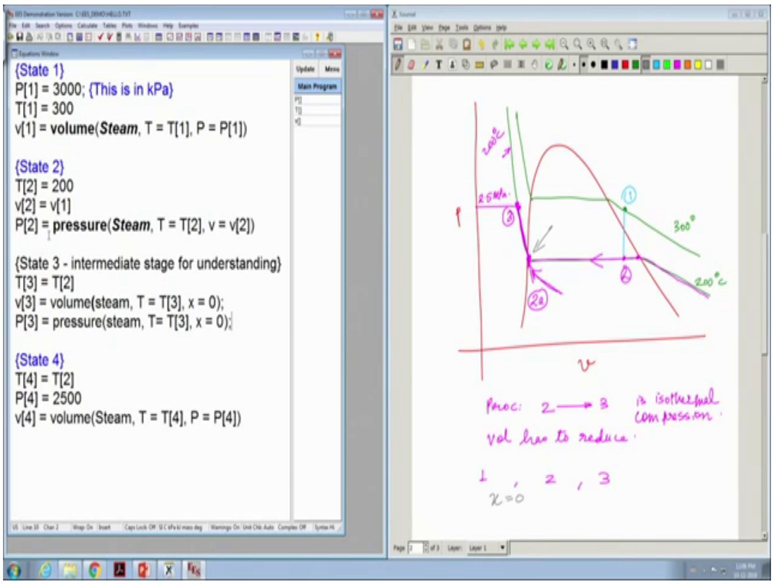

It went from 300 degree Celsius to 200 degree Celsius in a isochoric manner and then something wrong it has happened. But why then; obviously, we are not shifting like this let me try to justify by drawing another schematic. On a p v diagram isobars and the isotherms look something like this, this is 300 degree Celsius, it is 200 degree Celsius. So, this is tired off at a point over here this is 0.1 we end upon a point over here it is 0.2 and then process 2 to 3 is isothermal compression.

So, if it is isothermal compression it has to follow this particular line and because it is compression it has to go in this direction because during compression the volume as to reduce. So, up until the point it reaches this point let us call it as 2 a there is no change in pressure because once again I read a we are in the saturated dome from 0.2 to 2 a any change in the volume does not happen without change in pressure if the temperature is fixed the pressure will also be fixed.

After this point you compress isothermally you start going on this line, the reason being this is how the isotherm looks this is the same isotherm this is 200 degree Celsius isothermal. So, the final point lies somewhere over here and this corresponds to 2.5 mega Pascal. So, this point over here this is actually 2.5 mega Pascal, but what has happened is the computer says 3 points, 1, 2 and 3 and it simply joins them by a straight line.

So, this is where we have to understand at merely giving the computer values is not sufficient in order to understand actually what is going on, one must understand in a schematic manner what is the process which is going on ok. So, in order to actually have a true understanding of this process if you want to really plot the process what should we do, we have to obtain 0.2 a you have to actually obtain 0.2 a. So, then let us do it for completeness so, this becomes a state 4 it is just for a understanding ok.

So, T 3 is isothermal. So, this point I am calling as 3 now and that is isothermal so, because it is lying on the isotherm. So now, how else can I quantify that point I know the temperature how, what kind of property do I need do I know the volume no I do not know the volume I cannot guess the volume, what is the other property that we can use over here if you said it is a quality you are correct.

Because we have already seen at in the saturated dome it is the quality and some other property that we can used to quantify. So, x equal to 0 is a point on left limb of the saturated dome thus x. So, you can directly find v 3 equal to volume steam T equal to T 3 and x equal to 0, similarly T 3 will be pressure steam equal to T 3 and X equal to 0 just for completeness

So, let us now do the plot. So, we have already done the plot. So, let us go here and remove. So, let us go to plots overlay plot and on the x axis we have volume and on the y axis we have pressure let us do it by a red line and filled diamond markers maybe we have to first compile the program sorry because we have to run the program. So, that all the variables and now in the memory and now we go to plots property plot and even it opens up a new plot but we can make use of the old plot.

So, here we have to first remove the old plot we will remove the old plot double clicked on the figure and we get all the components of the figure, we have remove the all plot. And, now I can go to plot overlay plot on the x axis we have the volume, on the y axis you have the pressure and let us join it as this there you go.

So, this is how the process looks like this is point state 0.1 let me increase the marker size this is 0.1 this is 0. 2 this is 0. 3 this is 0. 4. So, this is how we go from 0.1 to 2 and then the isothermal process actually did takes it to first saturated liquid and then a sub cooled liquid and in the process of compression the pressure increases.

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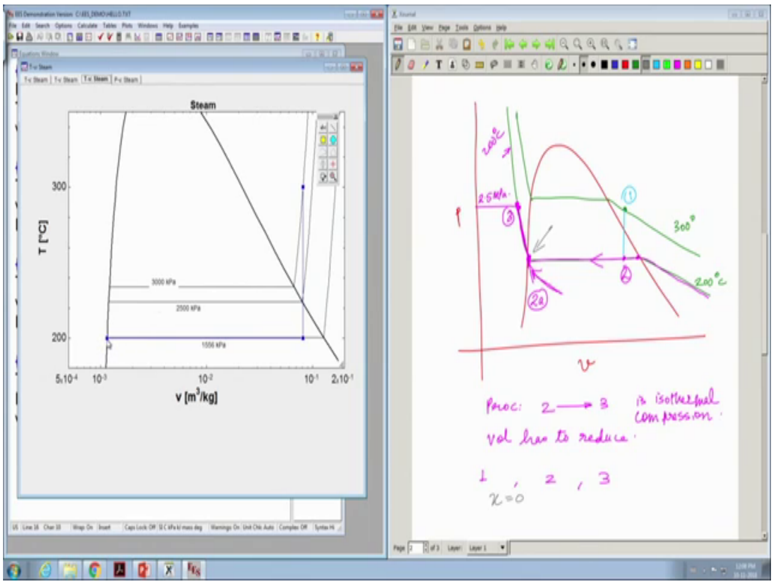

Even in the T v diagram we will see another point of we are in just at the boundary. So, plot over lay plot on the x axis we have the volume, on the y axis we have the temperature. So, this is a point just on the edge if we zoom in we can see. So, here you go I mean these are all numerical artifacts, but this point is on this line it is x equal to 0 and this point is in the sub cooled liquid. So, this is how you do it and I hope by means of this example you are convinced that one should always have a physical feel of the problem before attempting it. Because, that way you know where something is going wrong or whenever you are doing something this is maybe not physically realistic.

Like we saw the plot drew a straight line from state 2 to 3 and it was not a physically realistic thing, because isotherms do not behave that. So, you should have an idea of how p and v vary for an isotherm and in a T v diagram how a isobar looks like. So, just play around with the software, have a look into the property plots plot different isotherms plot different isobars. And, I will see you next time with another example alright.

Thank you.